Comparison of Standing Vegetation and Seed Bank Composition One Year Following Hardwood Reforestation in Southwestern Ohio[1]

CATHLENE I. LEARY AND CAROLYN HOWES-KEIFFER, Miami University, Department of Botany, Oxford, OH 45056

ABSTRACT: Successful conversion of pastures to forest is often hindered by the lack of structural complexity, which in turn reduces seed dispersal and recruitment of trees and shrubs. A long-term restoration study was initiated on a former pasture at the Fernald Environmental Management Project in southwestern Ohio. Our objective was to establish a planting design that has the potential to accelerate the restoration and succession of a site by creating structural complexity with uneven-aged stands of native trees. Changes in herbaceous vegetation composition were observed among the planting treatment by the end of the first growing season. We hypothesized that the vegetation differences could be attributed to recruitment from the seed bank following planting related disturbances. The standing vegetation and seed bank were evaluated to determine if differences in above-ground vegetation observed among plots could be explained by differences in composition of the seed bank. Using principle coordinates analysis (PCO), we found that herbaceous composition differed significantly (*P* <0.0001) from other planting treatments where high densities of saplings were planted, specifically due to a significant increase in perennial herbs (*P* <0.001). Based on cluster analysis, the seed bank and above-ground vegetation composition form two discrete groups, suggesting the seed bank does not fully account for standing vegetation. We attribute this compositional change to increased colonization via wind-dispersal and rhizome exposure of gaps created in the pasture grasses following planting disturbance. The results of this study suggest that disturbances related to restoration planting may dramatically alter the herbaceous vegetation composition of a site.

OHIO J SCI 104 (2):20–28, 2004

INTRODUCTION

In areas of human disturbance such as mines, closed landfills, and industrial sites, effective means of restoration are necessary to re-establish functional communities and habitats. Current literature suggests that the local landscape should serve as a template for such restoration activities (Handel and others 1994). However, in the eastern United States many abandoned degraded sites remain open, early successional fields in areas that were historically deciduous forests (Robinson and Handel 1993). Restoration specialists have recognized the need for reforestation strategies to accelerate the succession of such areas back to forest communities (Keddy and Drummond 1996).

From a community perspective, restoring disturbed areas to deciduous forest communities offers many benefits including providing habitat for wildlife, reducing soil erosion, and promoting nutrient cycling and biological productivity of soils (Peterken 1995; Miller 1998). Areas restored with native trees can connect with existing habitat fragments, enhancing the continuity of the local landscape (Handel and others 1994). The use of native tree species has also been shown to increase the potential for successful establishment and reproduction of planted stock (Butterfield 1995), which is advantageous for management purposes.

Ecological restoration of deciduous forest is grounded in community ecology theory and the processes of secondary succession (Young and others 2001). Studies of old-field succession have established the significant role that bird-dispersal plays in the development of deciduous forest communities (Pickett 1982; McDonnell 1986). McDonnell and Stiles (1983) found that an increase in structural complexity of old fields results in a significant increase in recruitment of bird-dispersed plant species. Hence the woody species, which extend above the existing matrix of herbaceous vegetation, act as recruitment foci attracting avian dispersers to the site. Because a large number of the mid-successional trees, shrubs, and woody vines of the eastern deciduous forests are bird-dispersed (Stiles 1980), the development of structural complexity within an herb-dominated community is an essential component in the transition from open field to forest.

A major temporal limitation to succession of restoration sites is that structure is very slow to develop, thereby creating areas that appear in an arrested state for several years. Such areas were noted on abandoned landfills in the New York metropolitan area and it has been suggested that they remain in this state due to seed dispersal limitations (Robinson and Handel 1993). Abandoned pastures dominated by weedy grasses can also persist for several years, with limited woody plant colonization (Nepstad and others 1991). Reduction in establishment of trees and shrubs has the potential to alter successional pathways for several years (Myster and Pickett 1994). Moreover, natural colonization of tree and shrub species is often limited by tall, introduced grass species that either invaded or were purposefully planted for erosion control.

One way to overcome the limitation of woody plant colonization is to provide the initial structure required

[1]Manuscript received 9 December 2002 and in revised form 20 November 2002 (#02-17).

to promote avian seed dispersal. The manipulation of a site to create structural complexity has been successfully applied to the restoration of deciduous forest communities, particularly with the use of saplings. Robinson and Handel (1993) found that planting sapling and shrub clusters resulted in an eight-fold increase in woody recruits compared to sites without planted trees. The majority (71%) of the tree and shrub species that established were bird-dispersed and originated from parent plants in nearby woodlot patches. This suggests that planting designs that incorporate multiple structural layers can be successful in encouraging dispersal, maximizing local woodlots as seed sources, and accelerating succession.

When management of grasses is limited, planted trees can play a significant role in suppressing grasses. The shade provided by emerging trees alters the local microclimate, allowing for a reduction in grass cover (Nepstad and others 1991). For example, Reay and Norton (1999) assessed three different forest restoration sites, each at varying time periods following planting (12, 30, and 35 years, respectively). They compared the restored areas to a grassland, which the sites resembled prior to planting, a naturally regenerating forest (100 years), and a remnant of original old-growth forest. They found that with increasing time after planting, there was a reduction in grass cover and the composition of the restored areas became more similar to the regenerating and mature forests. The rate of establishment and recolonization in the older restored sites (30, 35 years) was considered faster than those occurring under natural regimes, primarily due to slow woody plant colonization among competitive grasses of unplanted areas. These results indicate that if the barrier restricting succession is removed (overcoming limited natural colonization by planting woody species), the momentum of natural processes is strong enough to move the planting toward an indigenous forest.

A reforestation study was established on an abandoned pasture at the Fernald Environmental Management Project (FEMP) in southwestern Ohio. The objective of the study was to establish a planting design that enhanced succession by creating structural complexity using differing densities and size classes (saplings, seedlings) of deciduous trees. Approximately 6 months following planting, differences in vegetation among planting treatments were noted (Fig. 1). The large quantities of herbaceous perennials appearing at such an early stage of the reforestation process were not anticipated; particularly given the dense pasture grasses present at this site. An assessment of the initial success of the design was conducted 16 months following tree

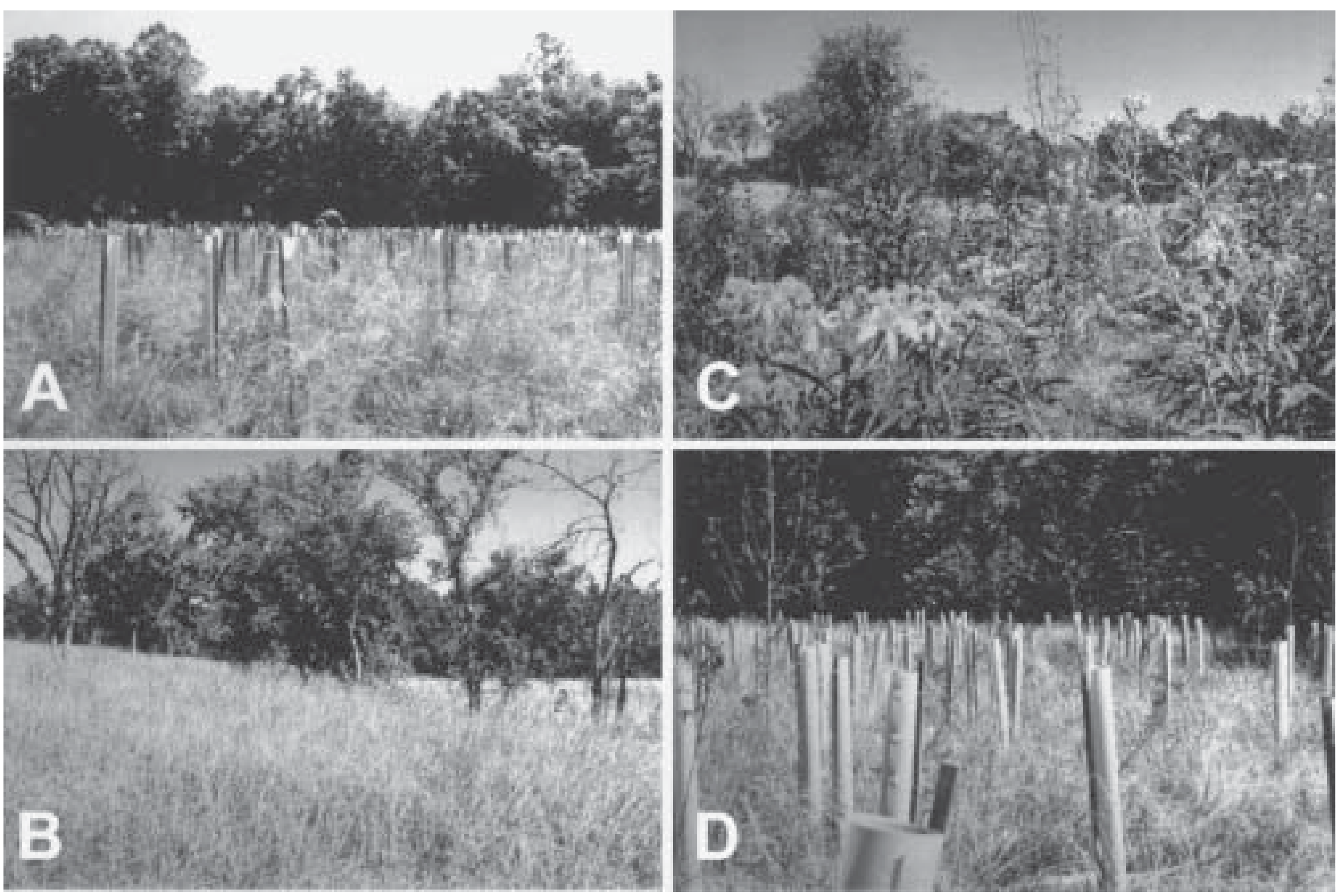

FIGURE 1. Photographs of three planting treatments and controls taken in September 1999, approximately six months following planting at the Fernald Environmental Management Project in southwestern Ohio. Treatments are as follows: A) seedling; B) control; C) sapling; D) mixed. Remnant forest areas are visible in the background of each photograph.

planting. We hypothesized that early vegetation changes could be an effect of seed bank exposure during tree planting.

Knowledge of seed banks has been utilized in several types of restoration activities such as mine reclamation (Zhang and others 2001; Farmer and others 1982) and the restoration of heathlands (Putwain and Gillham 1990); grasslands (Graham and Hutchings 1988; Bekker and others 1997); deciduous forests (Augosto 2001); and tropical systems (Skoglund 1992). Our objective was to determine what role the seed bank played in the development of the herbaceous vegetation layer at our reforestation site. An investigation was established among the planting treatments to determine if seed bank exposure significantly influenced the herbaceous vegetation matrix. The following questions were addressed in the study: Are there significant vegetation composition differences among planting treatments? If so, can these differences be a result of seed bank exposure? Specifically, what is the percent similarity of the above- and belowground species composition?

MATERIAL AND METHODS

Study Site

***History*:** This study was conducted at the Fernald Environmental Management Project (FEMP), a Department of Energy site located approximately 22 km south of Oxford, OH, and 20 km northwest of Cincinnati, OH (Fig. 2). The FEMP (ca. 425 ha) is located across both Hamilton and Butler counties near Morgan Township, an agricultural community of primarily dairy, beef, corn, and soybean production. From 1951 through 1991, this area was known as the Feed Materials Production Center. From 1952 to 1989, the facility produced purified uranium compounds and metals which were used in the production of nuclear weapons. The remediation and restoration of the site is managed under Fluor Fernald, Inc., a private organization under contract with the United States Department of Energy. Regulatory oversight is provided by the United States Environmental Protection Agency and the Ohio Environmental Protection Agency (Fernald Integrated Site Environmental Report 1999).

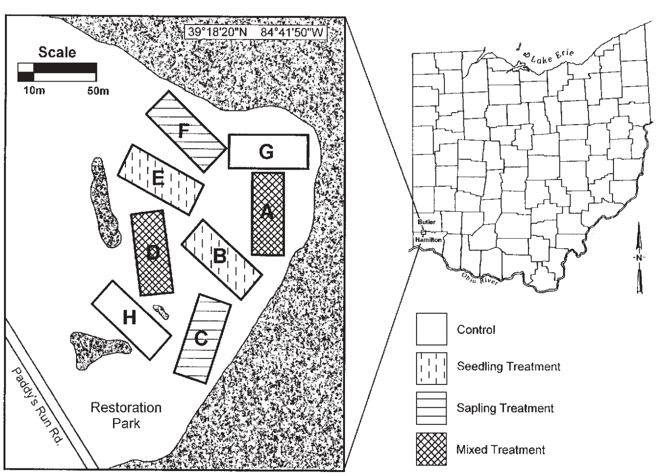

FIGURE 2. Location of the study area within the Fernald Environmental Management Project in southwestern Ohio. The boxed region within the map of Ohio represents the entire FEMP facility across Butler and Hamilton counties. A map of the Restoration Park area of the FEMP is included to show the location and layout of the study plots (A-H) and the designated treatments. Latitude and longitude coordinates mark the center of the study site.

The study site is an abandoned agricultural field included within the FEMP (39°18'20"N 84°41'50"W; USGS 1981). The specific site is adjacent to the FEMP facilities and was not contaminated during the uranium production years. Historical aerial photographs indicate that the area was used for farming prior to its purchase by the government in 1950. The site was never developed but was left as a buffer area for the adjacent FEMP facilities. Mowing occurred on the fields regularly through the late 1970s, when the area was leased to farmers for use in grazing livestock. Grazing and mowing disturbances continued on site until March 1998, when the lease agreement ceased, at which time the area was designated for ecological restoration research and became known as the Ecological Restoration Park. A portion of the park area is open to the public so that the restoration process can be observed.

The study site is bordered on the north by a woodlot that serves as a buffer between the study area and the existing FEMP facilities. A streambed, Paddy's Run, passes through the woodlot. To the east, a roadway, Paddy's Run Road, borders the site. The area generally slopes to the east and north from the roadway to the broad, level floodplain associated with the streambed.

***Vegetation*:** The FEMP is located in a transitional zone between two distinct sections of the eastern deciduous forest formation, the Oak-Hickory and the Beech-Maple forest communities (Braun 1950). This area was described by Braun (1936) as the Illinoian glaciation section of the Western Mesophytic Forest Region. Specifically, the riparian woodlot bordering Paddy's Run is described as resembling a Maple-Cottonwood-Sycamore Floodplain forest. The dominant species include eastern cottonwood (*Populus deltoides*), hackberry (*Celtis occidentalis*), American elm (*Ulmus americana*), and box elder (*Acer negundo*). Additional species found include black walnut (*Juglans nigra*), slippery elm (*Ulmus rubra*), and Ohio buckeye (*Aesculus glabra*) (Fernald Integrated Site Environmental Report 1999).

A 1993 herbaceous vegetation survey within the current Ecological Restoration Park area indicated that several introduced grassland species including *Poa compressa*, *P. pratensis*, *Festuca elatior*, and *Phleum pratense* dominated the area. In addition, common old field herbs included *Daucus carota*, *Ambrosia artemisiifolia*, and *Verbascum blattaria* (Site Wide Characterization report FEMP 1993).

***Geology, Soils, and Climate*:** From a geologic standpoint, the FEMP is located on the Till Plains section of the Central Lowland physiographic province. This section is characterized by the complete burial of preglacial features, producing a surface with relatively small relief. The glaciation of this area is considered recent (Illinoian and Wisconsin), therefore the plains have been largely preserved, in contrast to the western dissected section of the Till Plains, west of the Mississippi (Fenneman 1938). Specifically, the FEMP area underlies a 3.0 to 5.0

km-wide subterranean valley known as the New Haven Trough. The underlying bedrock is shale and fossiliferous limestone of the Middle and Late Ordovician age (Lerch and others 1993).

The soils of the study area are classified as Alfisols, characterized by a subsurface horizon in which silica has accumulated by illuviation (Brady and Weil 1996). The soil belongs to the Genesee series, consisting of deep, well-drained soils that formed in loamy alluvium on flood plains. Both permeability and organic matter content is moderate and this series is also subject to occasional brief flooding (Lerch and others 1993).

The regional climate is considered continental (Lerch and others 1993). The total precipitation measured at the FEMP during 1999 was 87.35 cm. The driest month was September, with a total precipitation of 3.30 cm, and the wettest month was June, with a total of 14.99 cm precipitation recorded. General wind direction data collected at the FEMP in 1999 revealed that the prevailing winds were from the west through south-southwest approximately 30 to 40% of the time. The mean wind speed for Hamilton County is highest (17 km hr^{-1}) in the winter (Lerch and others 1993).

Experimental Design

A portion of the woodlot adjacent to the study site was sampled in the summer of 1998 to provide a reference area or template for the restoration planting. This template served as a guide for the density, spatial pattern, and species selection of the planted nursery stock.

The census of the adjacent woodlot involved sampling of all stems with a diameter at breast height (DBH) >1.0 cm within three 0.1 ha plots. Results indicated that *Acer negundo* had the highest importance in each of the sampled plots (Plot 1 = 46%, Plot 2 = 33%, Plot 3 = 67%). Additional common species found among plots included *Celtis occidentalis*, *Platanus occidentals*, *Quercus bicolor*, and *Ulmus rubra*. Some less common species found included *Aesculus glabra*, *Fraxinus quadrangulata*, *Gleditisia triacanthos*, *Juglans nigra*, *Prunus serotina*, *Quercus muehlenbergii*, *Robinia pseudodacacia*, and *Maclura pomifera*. The sampling effort data were analyzed to determine which species would be most suitable for restoration planting. Selection criteria included successional stage, wildlife use, longevity, and susceptibility to insect damage. In addition, the commercial availability of the selected species at local nurseries was an important consideration. Based on the above criteria, the following species were selected for planting: *Aesculus glabra*, *Celtis occidentalis*, *Fraxinus pennsylvanica*, *Juglans nigra*, and *Quercus muehlenbergii*.

Eight (20 × 50 m) plots were established within the planned restoration area and were divided into three planting treatments, with two replicates of each: "seedling" (600 seedlings per plot), "mixed" (300 seedlings and 50 saplings per plot), and "sapling" (100 saplings per plot). Two control plots were left unplanted. The five species were equally represented in each planting treatment. Planting was completed in spring 1999, however the planting of *Quercus muehlenbergii* seedlings was delayed until spring 2000 due to unexpected low nursery stock availability. Twenty regularly-spaced permanent markers (rebar) were installed within the 8 plots in October 2000. These markers served as the sampling location for herbaceous vegetation sampling (Fig. 3).

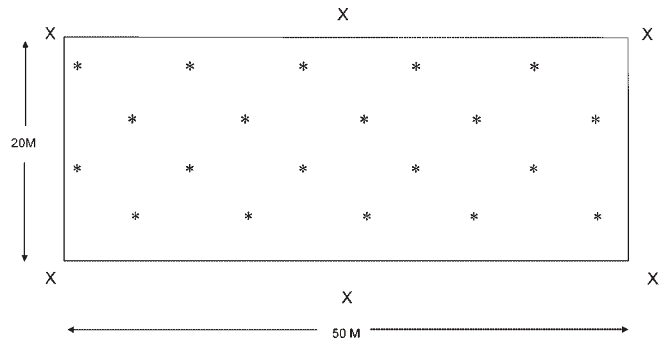

FIGURE 3. Diagram of individual field plot detailing the location of sampling events. Seed bank sampling (×) and herbaceous vegetation sampling (*).

The planting density was established based on the densities observed during sampling of the woodlot as well as information gathered from other riparian and upland forests (for example, Wistendahl 1958). The spatial pattern of the planted trees was determined by electronically mapping all of the trees (DBH >1.0 cm) within the three reference plots (0.1 ha each). One of the reference plots was randomly chosen to act as a spatial template for the study plots. The sapling treatment was determined by randomly assigning each of the 100 trees an X, Y coordinate from the mapped reference plots. A grid system was installed over the study plots (20 × 50 m), and color-coded flags were used to indicate a planting location. The seedlings were installed by generating a 10 × 10 m grid system based on the mapped reference plot. Each stem was then randomly assigned an X, Y coordinate. Ten of the 10 × 10 m subplots made up a single treatment plot (20 × 50 m). Each subplot was randomly rotated within the larger plot. The seedlings in the mixed treatments were established in the same manner; however, half of the sapling coordinates were randomly deleted from the template to obtain the desired density treatment.

Experiment 1: Vegetation Composition

To examine the effects of planted trees on herbaceous species composition, cover values of herbaceous species were estimated using a circular, 1.0 m^2 quadrat centered on each of the 20 permanent markers within the plots (Fig. 3). Sampling took place in early May, late June, and late August through early September 2000. A voucher collection was deposited at the William Sherman Turrell Herbarium, Miami University (nomenclature follows Gleason and Cronquist 1991).

Vegetation composition was statistically examined among treatments with the use of ordination. Principle coordinates analysis (PCO) was used to summarize species composition based on percent cover of each quadrat using MVSP (Kovach 1999). The chord distance measure was used in the principle coordinate analysis. Initial investigation of biplots revealed two quadrats that were considered outliers, therefore they were removed from this analysis. Mean PCO scores (axis one and two) from each treatment were ranked and tested for differences using a Kruskal-Wallis test.

An observation of increased perennial herb density in a planting treatment led to the examination of whether there was a relationship between planting treatments and perennial presence. Using the cover data collected at each permanent marker, the proportion of perennial herbs contributing to the overall cover was determined. A one-way ANOVA was used to examine differences in percent perennial cover among treatments using NCSS (Hintze 1999).

Experiment 2: Seed bank Analysis

Seed bank analysis using seedling emergence methods was conducted in the Boyd greenhouse, Miami University (Oxford, OH). Two soil cores (15 cm in depth, 7.5 cm in diameter) were taken in March 2000 from 6 sites around the perimeter of each plot (Fig. 3). The two soil cores per site ($N = 48$) were combined and were sieved (5.5 mm. mesh screen) to remove vegetation and rock debris. The soil was then spread on vermiculite in 20 × 20 cm flats. The flats were arranged randomly on a greenhouse bench and rotated weekly. Five control treatments (vermiculite only) were arranged among the soil treatments to detect greenhouse contamination. The trays were monitored weekly and presence-absence data recorded. After species were identified and recorded, they were removed from the trays. Unidentifiable species were transplanted from the trays to individual pots and grown to flower to aid in identification. After approximately 6 weeks, the soil was disturbed within each tray to promote any additional germination. At 8 weeks, no new germination was observed and the greenhouse experiment was concluded. Greenhouse temperature during the course of the study was maintained at approximately 24° C during the day and 20° C at night.

Sørensen's index was applied to presence-absence data, as described by Pielou (1984). The percent similarity between above- and below-ground species composition was quantified using UPGMA cluster analysis using PC-ORD (McCune and Medford 1999). The clustering remained robust with the use of two additional distance measures (Jaccards and Euclidean). The life-history of each species was documented, and a chi-squared analysis was used to determine if such attributes were independent between above- and below-ground vegetation using NCSS (Hintze 1999).

RESULTS

Experiment 1: Vegetation Composition

A principle coordinate analysis of the vegetation composition across treatments revealed an independent clustering of the vegetation found in the sapling treatment (Fig. 4A). A Kruskal-Wallis test of the first and second PCO scores revealed that the clustering of the sapling treatment at the first axis was not significant ($P > 0.05$, Fig. 4C), while the second axis was significant ($P < 0.001$, Fig. 4D). The relationship between percent perennial cover and planting treatment was also significant ($P < 0.001$, Fig. 4B). A Bonferonni multiple comparison test indicated that the mean percent perennials in the sapling treatment differed significantly from the mixed and seedling treatments, as well as the control. A species list for sampled vegetation is given in Appendix A.

Experiment 2: Seed bank Analysis

Results of the cluster analysis indicate that there is nearly 0% similarity between the above- and below-ground species composition among plots (Fig. 5). This suggests that vegetation found in above-round plots was more similar to other above-ground plots than to their corresponding below-ground plots. A comparison of life history types using a Chi-square analysis revealed a significant difference ($P < 0.05$) in the above- and below-ground life-history types (Fig. 6). A species list for seed bank vegetation is given in Appendix A.

DISCUSSION

The compositional difference in vegetation, quantified with a principle coordinates analysis, indicates that the herbaceous matrix was influenced by planting treatment. It was expected that three distinct clusters would be found: 1) the control and seedling treatment with little to no structure or planting disturbance, 2) the mixed treatments with structure (in moderate density) and moderate planting disturbance, and 3) the sapling treatment with structure (at greater density) and the greatest planting disturbance. However, the clustering of the sapling treatment suggests that the change in vegetation composition was confined to the areas with greatest sapling density and planting disturbance. Specifically, compositional differences appeared to result from an increase in cover of perennial herbs in the sapling treatment (Fig. 4B).

The relationship between both above- and below-ground species composition and life-history was strikingly different (Figs. 5, 6). Based on the current seed bank literature, these differences were expected (Thompson 1992). Forbs are generally more numerous than grasses in the seed bank (Rice 1989). The difference in the number of woody species found in the above- and below-ground was also anticipated due to the low number of tree seeds typically found in seed banks of old fields (Roberts and Vankat 1991; Tsuyukaki and Kanda 1996). The difference between the annuals in the above- and below-ground may be explained by differences in light availability. Some annual species have a light requirement for germination (Silvertown and Doust 1993); therefore, the optimal greenhouse conditions may have yielded a higher percentage of annuals compared to the field where patchy light conditions existed.

The exposure and germination of seeds via the seed bank may have attributed to some of the vegetation differences quantified in the sapling treatments. However, if the seed bank played a major role in the vegetation change, one would expect to see a clustering of sapling treatments with their corresponding seed bank samples.

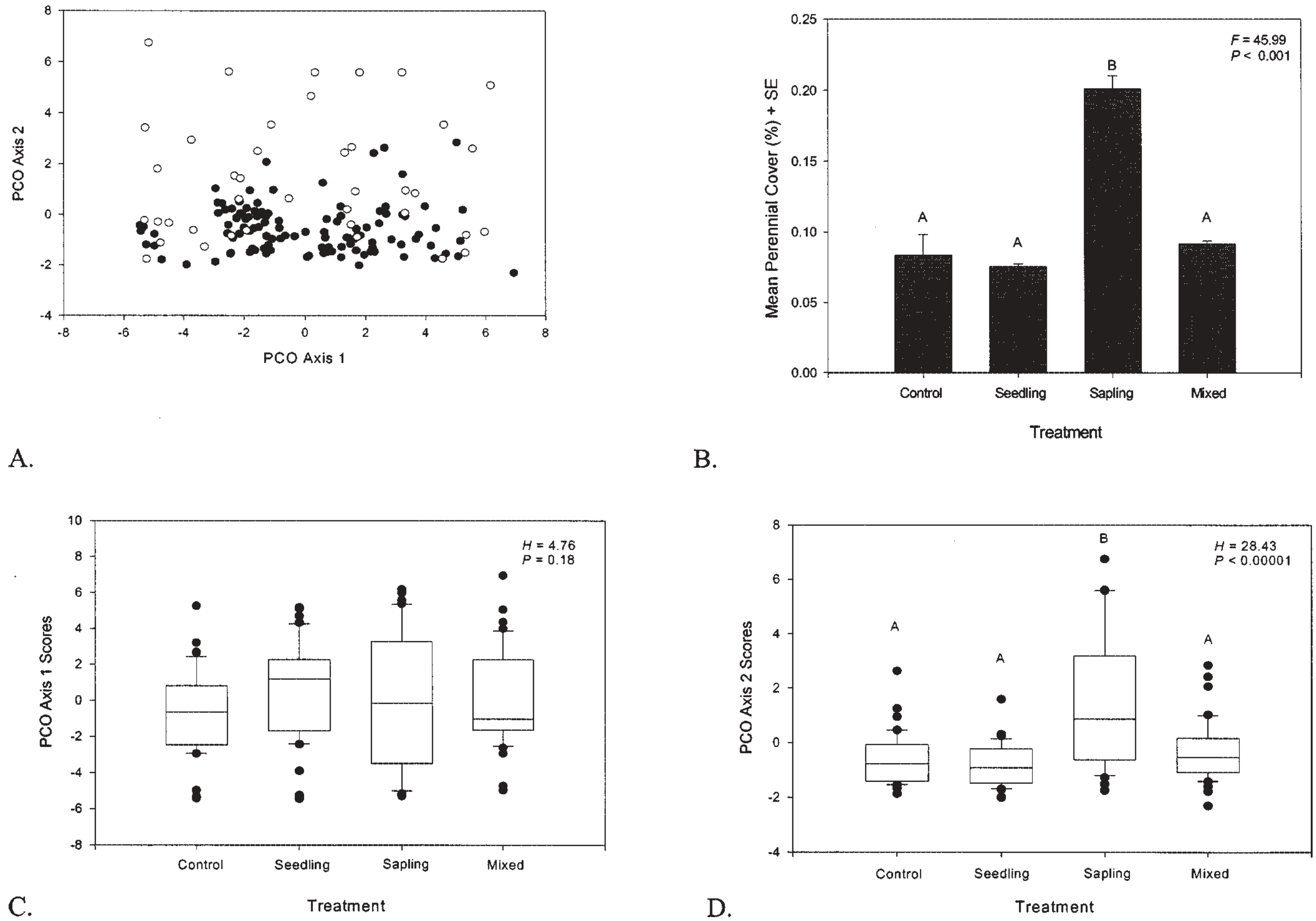

FIGURE 4. A.) Scatter plot of the first and second PCO scores (Chord distance measurement) for herbaceous vegetation data collected in the three planting treatments and control at the Fernald Environmental Management Project in southwestern Ohio. Filled points represent vegetation scores from control, seedling, and mixed treatments, and open points represent scores from sapling treatment. B.) Mean (+ standard error) of percent perennial cover of three planting treatments and control. (Significantly different values (P <0.001) are those labeled with different letters. Those numbers sharing the same letter are not significantly different.) C.) Box plot of PCO axis one scores for three planting treatments and control. The length of the box represents the interquartile range (IQR), with top and bottom of the box representing the 25th and 75th percentiles, respectively. The horizontal line within the box represents the median and the vertical lines extending from the box represent the 90th percentiles. Kruskal-Wallis test statistic (H) and P values produced via a Kruskal-Wallis test on ranked data. D.) Box plots of PCO axis two scores for three planting treatments and control. Kruskal-Wallis test statistic (H) and P values produced via a Kruskal-Wallis test on ranked data. (Significantly different values (P <0.001) are those labeled with different letters. Those numbers sharing the same letter are not significantly different.)

In fact, two of the perennial species whose high abundances were unique to the sapling treatments (*Vernonia gigantea* and *Verbesina alternifolia*) were not found in the seed bank.

However, there was evidence that the seed bank did have some influence on the vegetation change observed in the sapling treatment. For instance, *Erigeron annuus*, an annual species which typically germinates from the seed bank following disturbance in old fields (Armesto and Pickett 1985), was common to the seed bank throughout our site, yet its presence in the above-ground vegetation was limited to a replicate of the sapling treatment. This suggests that exposure of the seed bank related to planting disturbance did influence vegetation composition.

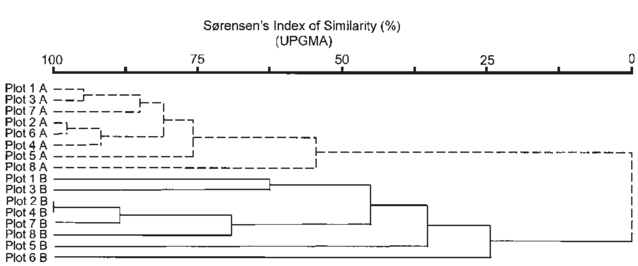

FIGURE 5. Unweighted pair group mean analysis (UPGMA) of above-ground herbaceous vegetation and seed bank sample at the plot scale using Sørensen's similarity coefficient. The above-ground plots, distinguished by the letter A and hashed lines, are representative of 20 quadrats per plot. The below-ground plots distinguished by the letter B and solid lines, are composed of six samples per plot.

The exact mode in which perennial species invaded the sapling treatment is difficult to determine. Perennials generally have low seedling emergence in undisturbed soil, relying primarily on vegetative reproduction for persistence in old fields (Goldberg and Gross 1988). However, many successfully colonize by seed following a soil disturbance (Goldberg and Gross 1988), making colonization by wind dispersal a potential explanation.

An experimental disturbance study by Kotanen (1997) indicated that species with bulbs had greater survival in overturned soil following a disturbance than perennial

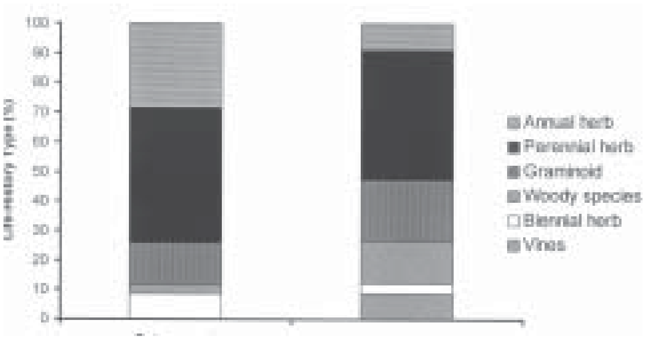

FIGURE 6. Comparison of life-history percentages between above- and below-ground species composition at the Fernald Environmental Management Project in southwestern Ohio. A chi-squared test indicated that a significant (*P* <0.05) difference exists between the life-history types of below-ground and above-ground groups.

graminoids. Therefore, the planting disturbance may have exposed rhizomes suppressed beneath the dense turf, causing an increase in perennial herbs, while negatively impacting the existing grass sward. This may explain the high frequency of *Vernonia gigantea*, a perennial species with an underground organ of axillary buds responsible for vegetative reproduction (Mann and others 1983). In the same study, the authors pointed out that soil disturbance often exposes a deeper region of subsoil which generally lacks seeds. This may explain the extremely low similarity between the species present in the seed bank and those found in the sapling treatment.

One would anticipate that the effects of an intermediate level of disturbance would have been detected within the mixed treatment; however, this was not the case. There are several possible explanations to account for why this may have occurred. First, there were obvious differences in the intensity of soil disturbance between the mixed and the sapling treatments. For instance, in both replicates of the sapling treatment there were clods and mounds of exposed soil near planted saplings that were not observed in the mixed treatments. It is difficult to determine why this may have occurred. It could simply be an artifact of the difference in planting crews over the two-week period when the trees were installed. Another possibility is that the weather, more specifically the soil moisture content at the time of planting, influenced clod formation.

The significant effect of planting disturbance on herbaceous vegetation may have a considerable influence through time. The increase in tall perennial herbs, like *Vernonia gigantea* and *Verbesina alternifolia*, created an additional vegetation structure layer in the sapling treatment. A study that examined this bi-layer structure using *Solidago canadensis* demonstrated that significant microclimate changes occur beneath the closed canopy of this species, affecting species composition and abundance (Armesto and Pickett 1985). Gill and Marks (1991) found higher woody seedling emergence in the presence of long-lived perennial herbs compared to annuals and biennials or bare soil; however, the strong competition for light, moisture, and nutrients with dominant perennial herbs may limit woody plant establishment, particularly on rich soils (Smit and Olff 1998). Therefore, this early vegetation difference among treatment plots has the potential to influence the rate of tree and shrub invasion and succession.

The results of this study suggest that seed bank exposure had only a minor influence in the difference in herbaceous vegetation among planting treatment. However, small-scale disturbance associated with planting did influence species composition and establishment within the matrix of dominant grasses. From an applied standpoint, the role of soil disturbance should be considered as a significant component when planting saplings, particularly in grass-dominated areas. Although many of the species that established following planting were native, mid-successional perennial herbs, it is well documented that soil disturbance has the potential to promote invasive, non-native species (Hobbs and Huenneke 1992; Kotanen 1997). It is therefore necessary to develop a management plan for invasive species in conjunction with the restoration planting.

ACKNOWLEDGEMENTS. We extend sincere thanks to the following organizations and people: Sigma Xi Grants-in-Aid of Research, the Department of Botany at Miami University, and the Garden Club of Ohio for their financial support of this research; the Fernald Environmental Management Project for their cooperation, and Dr. Brian McCarthy for his statistical and editorial comments. We also thank the two anonymous reviewers for their comments and suggestions which improved the content of this manuscript.

LITERATURE CITED

Armesto JJ, Pickett STA. 1985. Experiments on disturbance in old-field plant communities: impacts on species richness and abundance. Ecology 66:230-40.

Augusto L, Dupouey J, Picard J, Ranger J. 2001. Potential contribution of the seed bank in coniferous plantations to the restoration of native deciduous forest vegetation. Acta Oecologica 22(2):87-98.

Bekker RM, Verweij GL, Smith REN, Reine R, Bakker JP, Schneider S. 1997. Soil seed banks in European grasslands: does land use affect regeneration perspectives? J Appl Ecol 34:1293-1310.

Brady NC, Weil RR. 1996. The Nature and Properties of Soils. 11th edition. Upper Saddle River (NJ): Prentice Hall.

Braun EL. 1936. Forests of the Illinoian till plain of southwestern Ohio. Ecological Monographs 6:90-149.

Braun EL. 1950. Deciduous forests of North America. New York (NY): Hafner Pr.

Butterfield RP. 1995. Promoting biodiversity: advances in evaluating native species for reforestation. Forest Ecol and Management 75:111-21.

Farmer RF Jr, Cunningham M, Barnhill MA. 1982. First Year development of plant communities originating from forest topsoils placed on southern Appalachian minesoils. J Appl Ecol 19:283-94.

Fenneman NE. 1938. Physiography of Eastern United States. London (UK): McGraw-Hill.

Fernald Integrated Site Environmental Report. 1999. Fernald Environmental Management Project. Fluor Fernald, Inc., Cincinnati, OH.

Gill DS, Marks PL. 1991. Tree and shrub seedling colonization of old fields in central New York. Ecological Monographs 61:183-205.

Gleason HA, Cronquist AC. 1991. Manual of vascular plants of northeastern United States and adjacent Canada. New York Botanical Garden, Bronx, NY.

Goldberg DE, Gross KL. 1988. Disturbance regimes of midsuccessional old fields. Ecology 69:1677-88.

Graham DJ, Hutchings MJ. 1988. Estimation of a chalk grassland ley established on former arable land. J Appl Ecol 25:241-52.

Handel SN, Robinson GR, Beattie AJ. 1994. Biodiversity resources for restoration ecology. Restoration Ecology 2:230-41.

Hintze JL. 1999. Number cruncher statistical software. Kaysville, UT.

Hobbs RJ, Huenneke LF. 1992. Disturbance, diversity, and invasion: implications for conservation. Conservation Biology 6:324-37.

Keddy PA, Drummond CG. 1996. Ecological properties for the evaluation, management and restoration of temperature deciduous forest ecosystems. Ecological Applications 6:748-62.
Kotanen PM. 1997. Effects of experimental soil disturbance on revegetation by natives and exotics in coastal California meadows. J Appl Ecol 34:631-44.
Kovach WL. 1999. MVSP - A multivariate statistical package for windows. Ver. 3.1. Kovach Computing Services, Pentraeth, Wales, UK.
Lerch NK, Hale WF, Lemaster DD. 1993. Soil survey of Hamilton County, Ohio. USDA, Soil Conservation Service. Washington, DC.
Mann RK, Rosser SW, Witt WW. 1983. Biology and control of tall ironweed (*Vernonia altissima*). Weed Science 31:324-8.
McCune B, Medford MJ. 1999. PC-ORD. Multivariate analysis of ecological data. Ver. 4. MJM Software Design, Glendale Beach, OR.
McDonnell MJ. 1986. Old field vegetation height and the dispersal pattern of bird disseminated woody plants. Bull of the Torrey Botanical Club 133:6-11.
McDonnell MJ, Stiles EW. 1983. The structural complexity of old field vegetation and the recruitment of bird-dispersed plant species. Oecologia 56:109-16.
Miller S. 1998. Successful tree planting techniques for drastically disturbed lands: a case study of the propagation and planting of container-grown oak and nut trees in Missouri. National Meeting of the American Society for Surface Mine Reclamation, St. Louis, MO, 17-22 May 1998.
Myster RW, Pickett STA. 1994. A comparison of rate of succession over 18 yr in 10 contrasting old fields. Ecology 75:387-92.
Nepstad DC, Uhl C, Serrao ESA. 1991. Recuperation of a degraded Amazonian landscape: forest recovery and agricultural restoration. Ambio 20:248-55.
Peterken GF. 1995. Foreword: an overview of native woodland creation. Pages x-xvii. In: Ferris-Kaan R, editor. The Ecology of Woodland Creation. Chichester (UK): John Wiley.
Pickett STA. 1982. Population patterns through twenty years of old field succession. Vegetatio 49:45-59.
Pielou EC. 1984. The interpretation of ecological data: a primer on classification and ordination. New York (NY): Wiley Interscience Publ.
Putwain PD, Gillham DA. 1990. The significance of the dormant viable seed bank in the restoration of heathlands. Biological Conservation 52:1-16.
Reay SD, Norton DA. 1999. Assessing the success of restoration planting in a temperate New Zealand forest. Restoration Ecology 7:298-308
Rice J. 1989. Impact of seed banks on grassland community structure and population dynamics. In: Leck MA, Parker VT, Simpmson RL, editors. The Ecology of Seed Banks. San Diego (CA): Academic Press. p 211-30.
Roberts TL, Vankat JL. 1991. Floristics of a chronosequence corresponding to old field deciduous forest succession in southwestern Ohio. II. Seed Banks. Bull of the Torrey Botanical Club 118:377-84.
Robinson GR, Handel SN. 1993. Forest restoration on a closed landfill: rapid addition of new species by bird dispersal. Conservation Biology 7:271-7.
Silvertown JW, Doust JL. 1993. Introduction to plant population biology. Oxford (UK): Blackwell Scientific Publ.
Site Wide Characterization Report: Fernald Environmental Management Project. 1993. US Dept of Energy, Cincinnati, OH.
Skoglund J. 1992. The role of seed banks in vegetation dynamics and restoration of dry tropical ecosystems. J Vegetation Sci 3:357-60.
Smit R, Olff H. 1998. Woody species colonization in relation to habitat productivity. Plant Ecol 139:203-9.
Stiles EW. 1980. Patterns of fruit presentation and seed dispersal in bird disseminated woody plants in the eastern deciduous forest. Amer Naturalist 166:670-88.
Thompson K. 1992. The functional ecology of seed banks. In: Fenner M, editor. Seeds, the Ecology of Regeneration in Plant Communities. Wallingfold (UK): CAB International. p 231-58.
Tsuyukaki S, Kanda F. 1996. Revegetation patterns and seed bank structure on abandoned pastures in Northern Japan. Amer J Botany 83:1422-8.
[USGS] United States Geological Survey. 1981. Shandon (OH) quadrangle, 7.5 minute series (topographic) map, 1:24000 scale. Reston (VA): USGS.
Wistendahl WA. 1958. The floodplain of Raritan River, New Jersey. Ecological Monographs 28:129-53.
Young TP, Chase JM, Huddleston RT. 2001. Community succession and assembly: comparing, contrasting, and combining paradigms in the context of ecological restoration. Ecological Restoration 19:5-18.
Zhang ZQ, Shu WS, Lan CY, Wong MH. 2001. Soil seed bank as an input of seed source in revegetation of lead/zinc mine tailings. Restoration Ecology 9:378-85.

Appendix A

Species list of standing vegetation and presence in seed bank for vegetation sampled at the FEMP in southwestern Ohio.

Taxon	Seed Bank
Acalypha viginica var. *rhomboidea* Raf.	
Acer negundo L.	Present
Achillea millefolium L.	Present
Aesculus glabra Willd.	
Allium vineale L.	
Ambrosia artemisiifolia L.	
Ampelamus albidus (Nutt.) Britton.	
Asclepias syriaca L.	
Aster pilosus Willd.	
Brassica nigra L.	
Bromus inermis Leysser.	
Campsis radicans (L.) Seemann.	
Carex amphibola Steudel.	Present
Carex vulpinoidea Michx.	
Carya cordiformis (Wagenh.) Koch	
Celtis occidentalis L.	
Cerastium fontanum L.	Present
Chenopodium album L.	Present
Convolvulus arvensis L.	
Conyza canadensis (L.) Cronq.	Present
Cirsium arvense (L.) Scop.	
Dactylis glomerata L.	
Daucus carota L.	Present
Desmodium canadense (L.) DC.	
Erigeron annuus (L.) Pers.	Present
Eupatorium rugosum Houttuyn.	
Euphorbia nutans Lagasca.	Present
Festuca elatior L.	
Galium aparine L.	
Geum vernum (Raf.) T. & G.	Present
Glechoma hederacea	Present
Gleditsia triacanthos	
Juglans nigra L.	
Juncus tenuis Willd.	
Lamium purpurem L.	
Lysimachia nummularia L.	

Appendix A (*Cont.*)

Species list of standing vegetation and presence in seed bank for vegetation sampled at the FEMP in southwestern Ohio.

Taxon	Seed Bank
Medicago lupulina L.	Present
Melilotus alba Medikus.	Present
Mollugo verticillata L.	Present
Muhlenbergia racemosa (Michx.)	Present
Oxalis stricta L.	Present
Parthenocissus quinquefolia L.	
Paspalum pubiflorum Rupr.	
Phleum pratense L.	
Phytolacca americana L.	Present
Physalis longifolia Nutt.	
Plantago lanceolata L.	
Plantago rugelii Decne.	Present
Platanus occidentalis L.	
Poa pratensis L.	Present
Polygonum punctatum Elliott.	Present
Prunus serotina Ehrh.	
Rumex acetosella L.	
Setaria glauca (L.) P. Beauv.	Present
Solanum carolinense L.	Present

Appendix A (*Cont.*)

Species list of standing vegetation and presence in seed bank for vegetation sampled at the FEMP in southwestern Ohio.

Taxon	Seed Bank
Solanum dulcamara L.	Present
Solidago canadensis L.	Present
Stellaria media (L.) Villars.	
Taraxacum officinale Weber.	Present
Toxicodendron radicans (L.) Kuntze.	
Tradescantia ohiensis Raf.	Present
Tridensflavus (L.) A. Hitchc.	
Trifolium pratense L.	Present
Trifolium repens L.	
Ulmus rubra Muhl.	Present
Verbena urticifolia L.	Present
Verbascum blatteria L.	Present
Verbesina alternifolia (L.) Britton.	
Vernonia gigantea (Walter) Trel.	
Veronica arvensis L.	Present
Viola sororia Willd.	Present
Vitis vulpina L.	